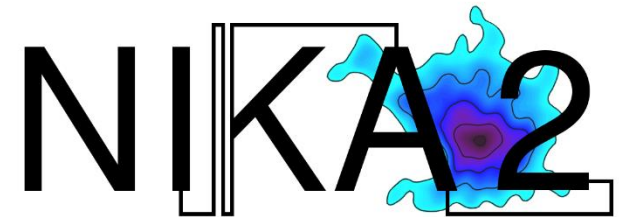


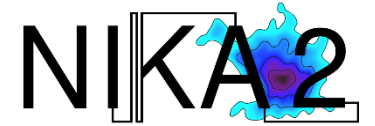
High-resolution SZ cartography of clusters of galaxies with NIKA at the IRAM 30-m telescope

F. Mayet

on behalf of the NIKA2 Collaboration

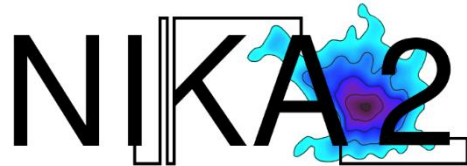


Outline

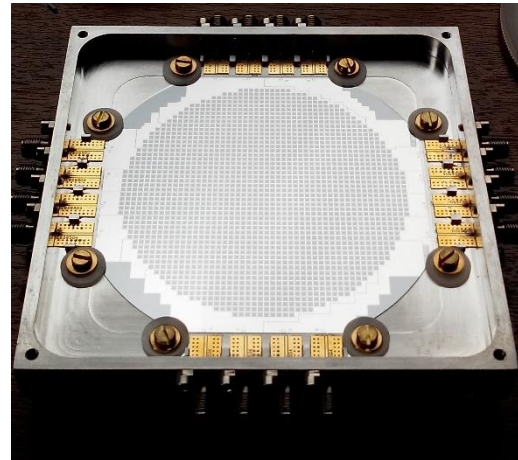


1. The NIKA2 camera
and the NIKA prototype
2. Why high-resolution SZ cartography of clusters ?
3. SZ observations with NIKA
 - well-known cluster
 - high-z cluster
 - Planck-discovered cluster
4. The NIKA2 SZ large program (2017-2022)
 - follow-up of Planck-discovered clusters

High-resolution SZ cartography of clusters of galaxies with **the NIKA camera** at the IRAM 30-m telescope



NIKA2 LEKID array (260 GHz)

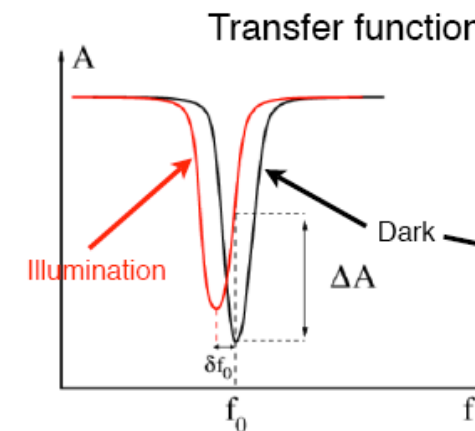


The NIKA2 camera



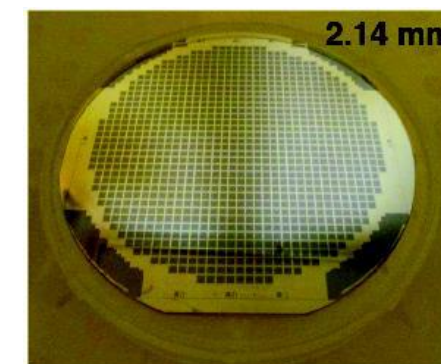
NIKA2

- KID-based camera
 - Kinetic Inductance Detectors = High quality factor superconducting resonators
 - Frequency shift proportional to the incoming optical power*
- Operated at 100 mK
- Dual-band: 150 and 260 GHz
- Wide field of view: 6.5 arcmin (spec) -3300 detectors
- High-angular resolution: 18 and 12 arcsec (spec.)
- State-of the art sensitivity : 20 and 30 mJy.s^{1/2} (spec.)
- Polarization capabilities at 260 GHz



NIKA

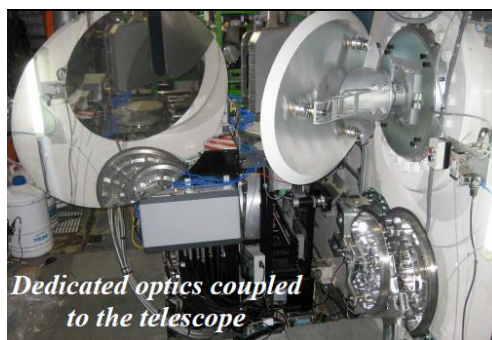
- a prototype of NIKA2
- operated at IRAM-30m telescope from 2014 to 2015
- Field of view: 1.8 arcmin (356 detectors)



The NIKA2 camera



IRAM 30-m telescope
at Pico Veleta (Spain)



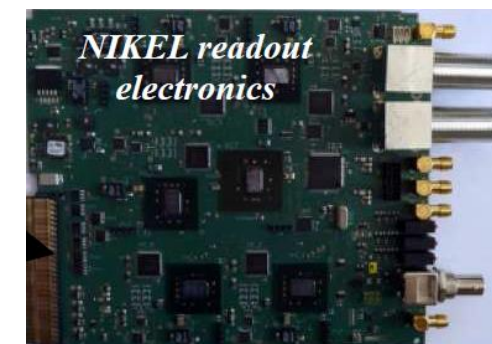
The NIKA2 camera has been built by the NIKA2 Collaboration

- 14 laboratories
- 110 members of the collaboration

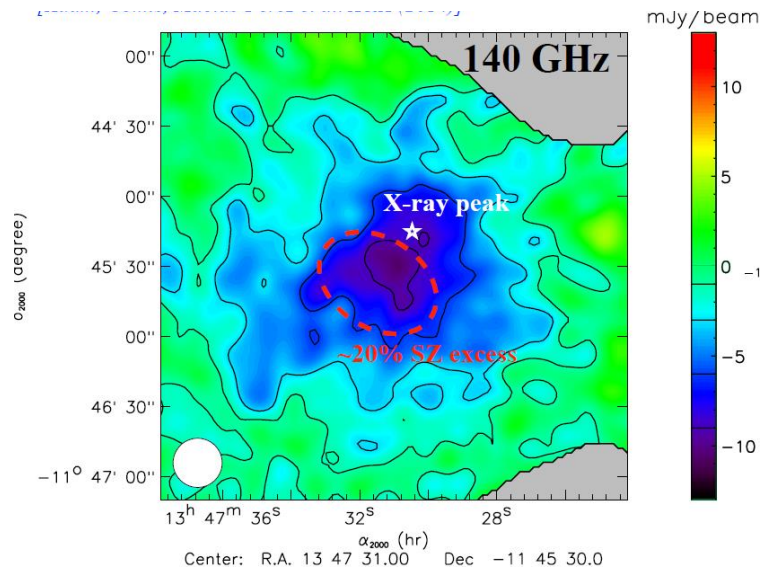
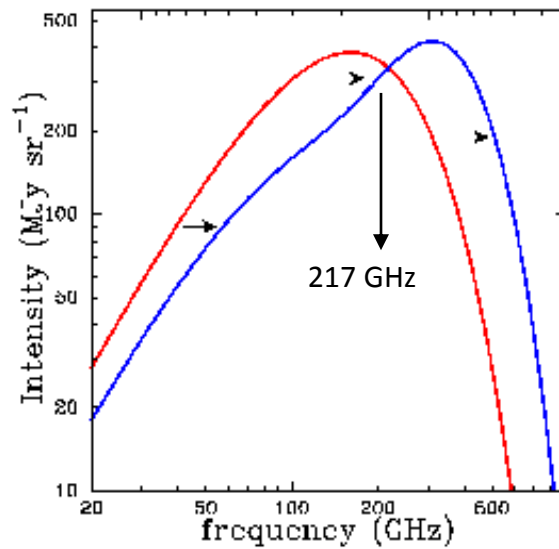


The NIKA2 camera

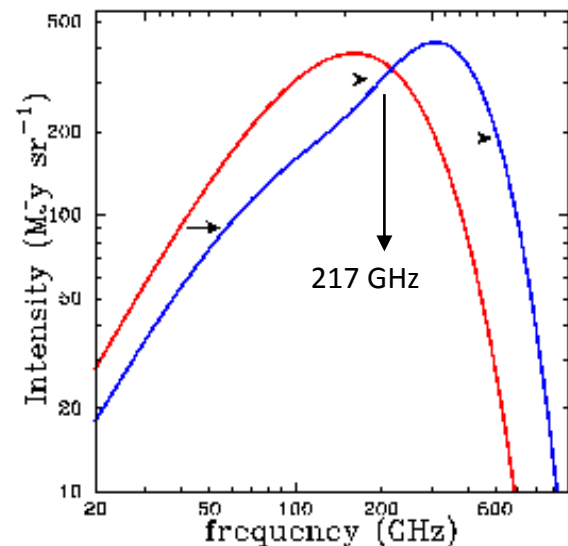
- has been installed in Sep. 2015 at the **IRAM-30m telescope**
- has given its **first light** in Oct. 2015 and is being commissioned
- will be **open to the scientific community for the next decade**



High-resolution Sunyaev Zel'dovich cartography of clusters of galaxies with NIKA at the IRAM 30-m telescope



Sunyaev Zel'dovich (SZ) Effect



Thermal Sunyaev Zel'dovich effect (SZ)

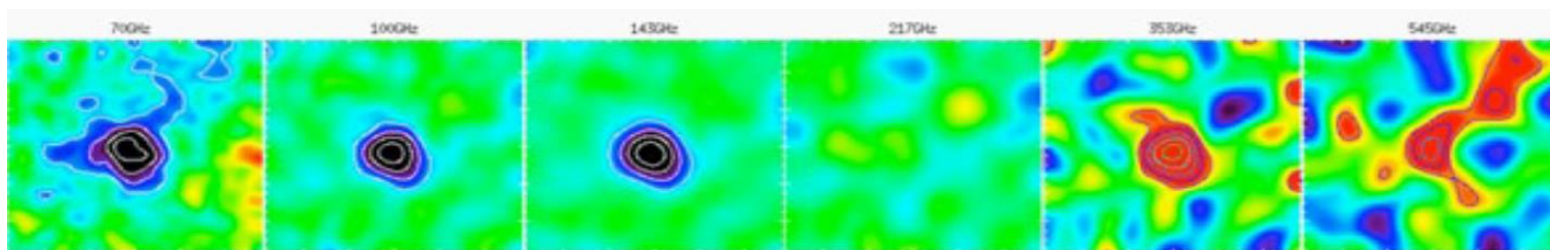
- inverse Compton scattering of CMB photons on hot electrons of the intra-cluster medium (ICM)
- spectral distortion of the CMB spectrum
 - SZ effect is redshift-independent
 - observation of high-z clusters

→ Compton parameter

$$y \propto \int P_e dl$$

→ Characterization of the electronic pressure (shocks)

A 2319
(Planck)



70 GHz

100 GHz

145 GHz

★
NIKA
150

217 GHz

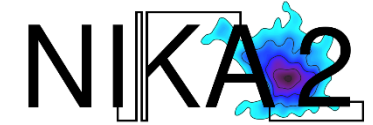
★
NIKA
260

343 GHz

545 GHz

Frequency →

Why high-resolution SZ cartography of clusters ?



- Clusters of galaxies are widely used for cosmological studies
- Catalog of ~2000 galaxy clusters identified by their SZ signal by Planck, ACT and SPT

- NIKA2 resolution is ~30 times better than Planck's one
- high-resolution cartography
- Study of the **intra-cluster medium (ICM)**

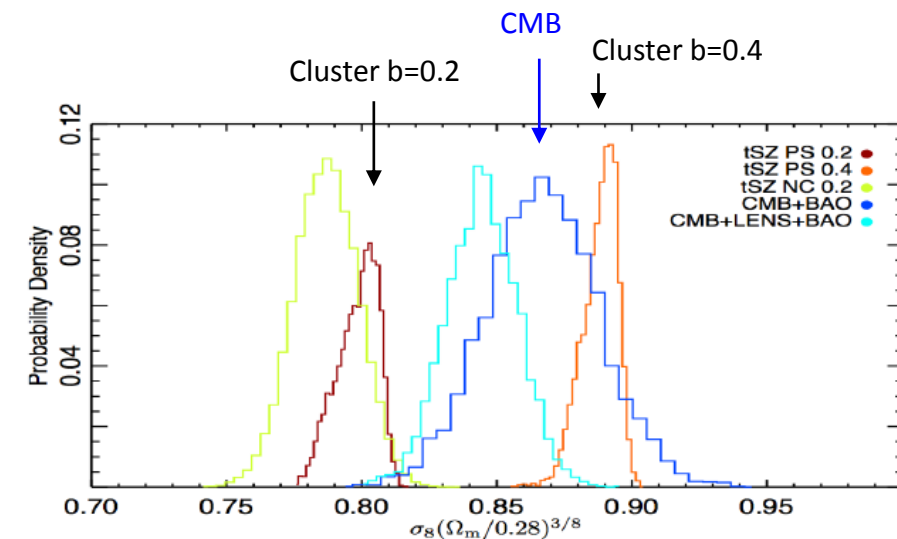
- **Tension** between CMB and Cluster estimation of cosmological parameters
... most probably due to the estimation of **the total mass** of the cluster

$$M_{tot} = (1 - b)M_{HSE} \quad \text{where } b \text{ is the hydrostatic bias}$$

High-resolution observations would allow us to study

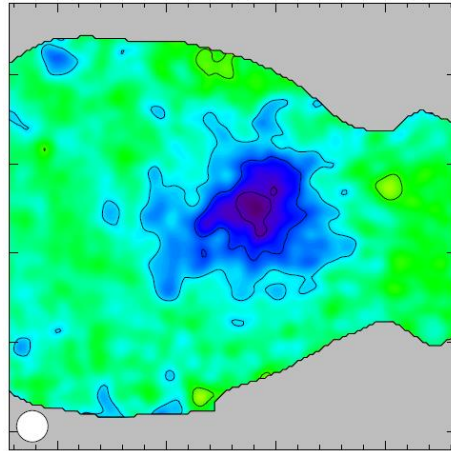
- the **hydrostatic bias**
- the pressure distribution within the **inner part of the cluster**
- the **redshift dependence of the pressure profile**

- Combined with other probes (X-ray, lensing) = **multi-probe analysis of clusters**
- this will open a **new era for the use of clusters to study cosmology.**



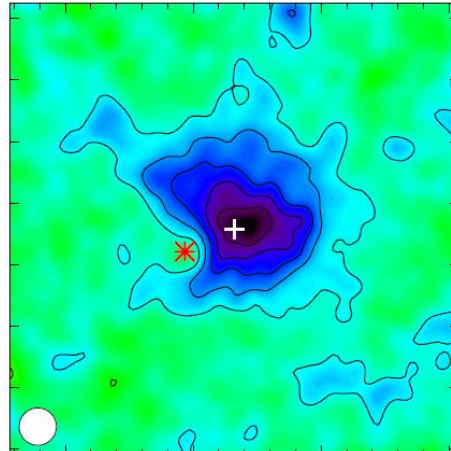
SZ observations with NIKA

RXJ1347



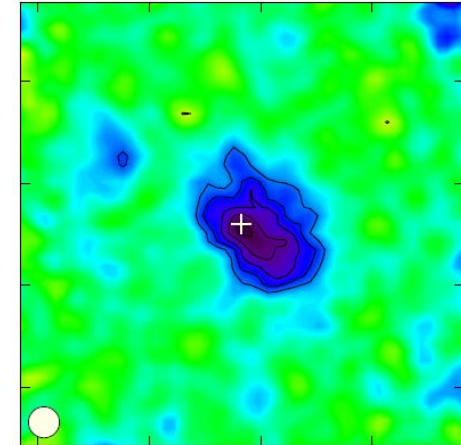
well-known

CLJ1227



high-z

PSZ1G045

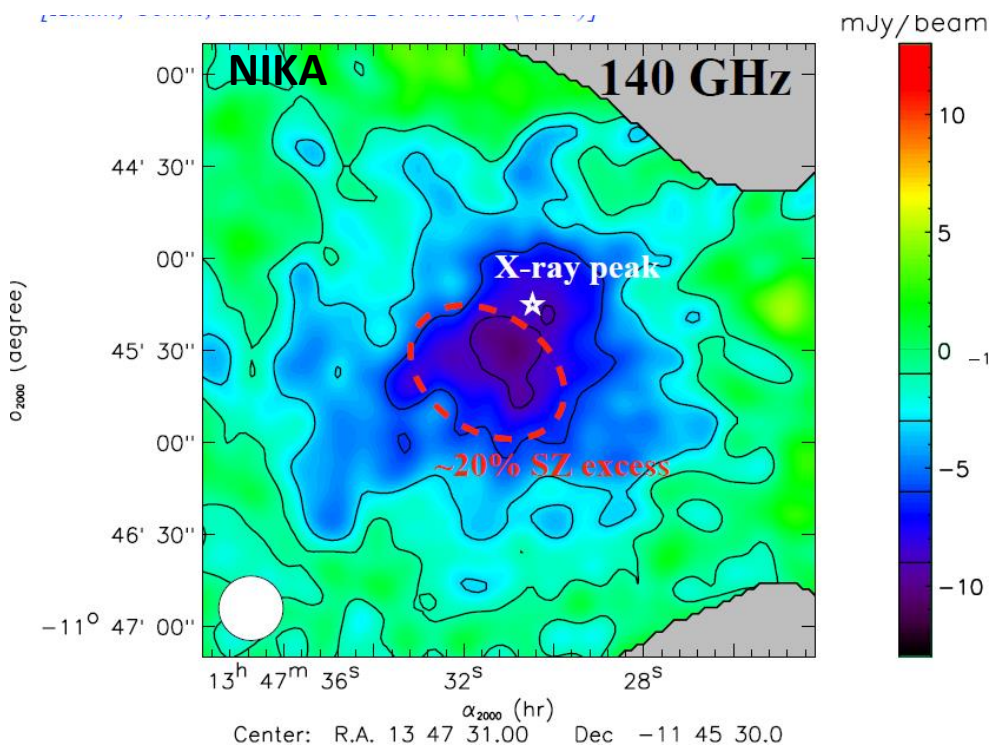


Planck-discovered

Well-known cluster: RX J1347 (z=0.45)



Nov. 2012
Obs. time: 5.5 h
R. Adam *et al.*, A&A 2014



RXJ1347

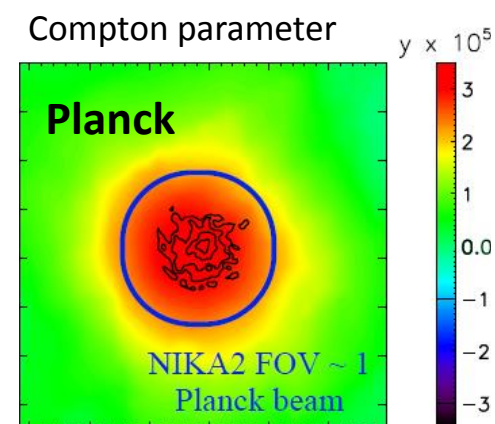
- the most luminous X-ray cluster
- strong SZ signal (Diabolo, Mustang, Carma)

Data analysis: *Single-band method*

Atmospheric noise removal performed by using the 260 GHz data as a template (*as the expected SZ signal is small*)

- 10σ detection
- First observation of SZ effect with a KID-based camera (NIKA)
- NIKA2 field of view = Planck beam

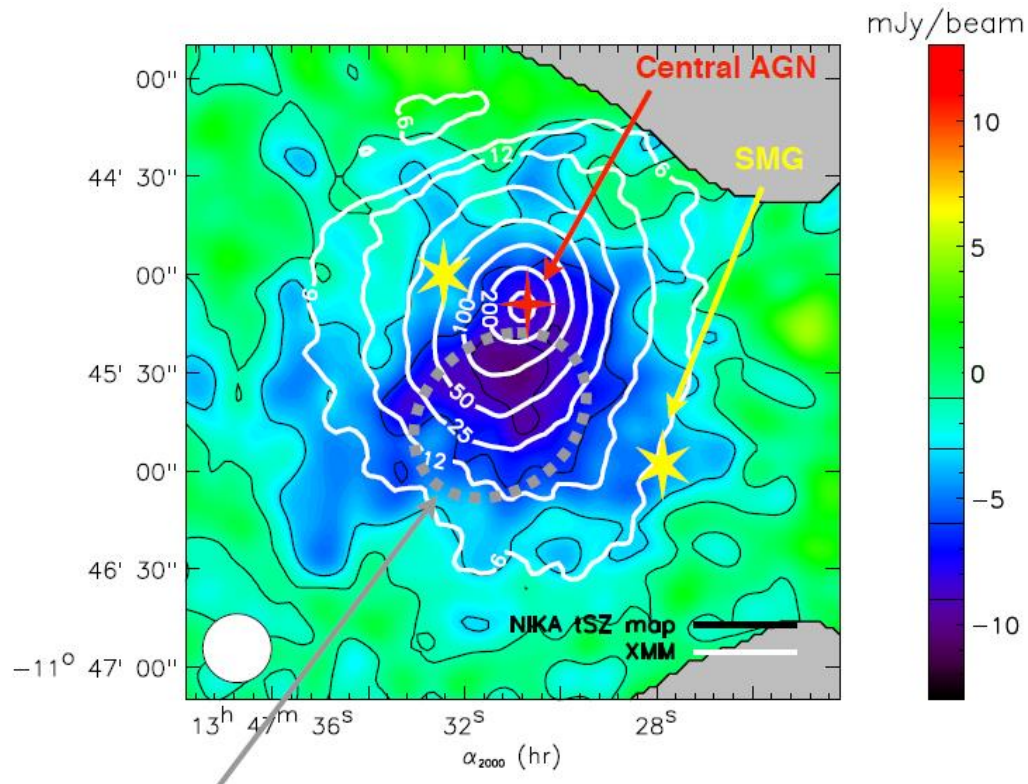
→ The combination of Planck and NIKA data allows us to study the ICM at all scales (core and outskirts)



Well-known cluster: RX J1347 (z=0.45)



Nov. 2012
Obs. time: 5.5 h
R. Adam *et al.*, A&A 2014



Multi-probe study: X, radio, optical

$$X \text{ ray} \propto n_e^2 \sqrt{T_e}$$

$$SZ \propto P_e \propto n_e T_e$$

→ SZ used to characterize shocks

Conclusions:

→ X-ray peak (XMM) well aligned on central AGN

→ SZ peak shifted toward South-East
& agrees with radio halo

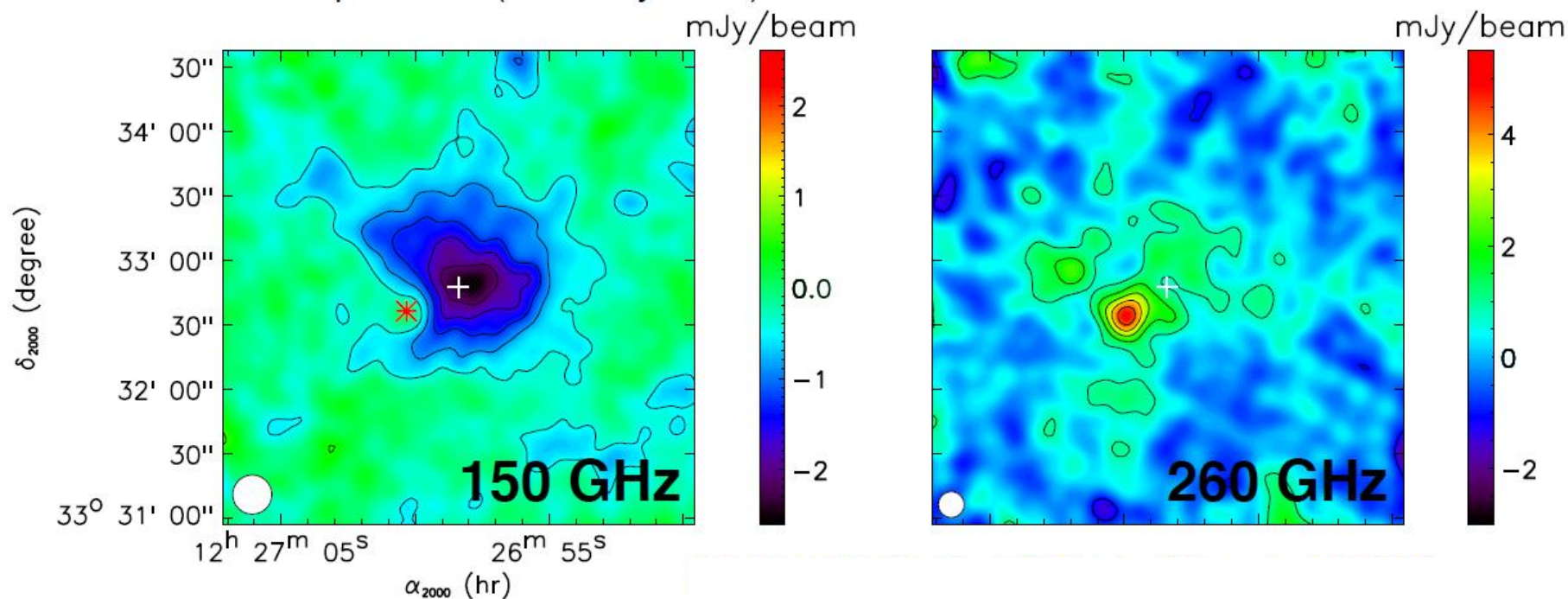
→ RXJ1347 is an on-going merger

→ This first observation highlights the interest of high-resolution cartography with NIKA

High-z cluster: CL J1227 ($z=0.89$)



Feb. 2014
 Obs. time: 7.8 h
 R. Adam *et al.*, A&A 2015

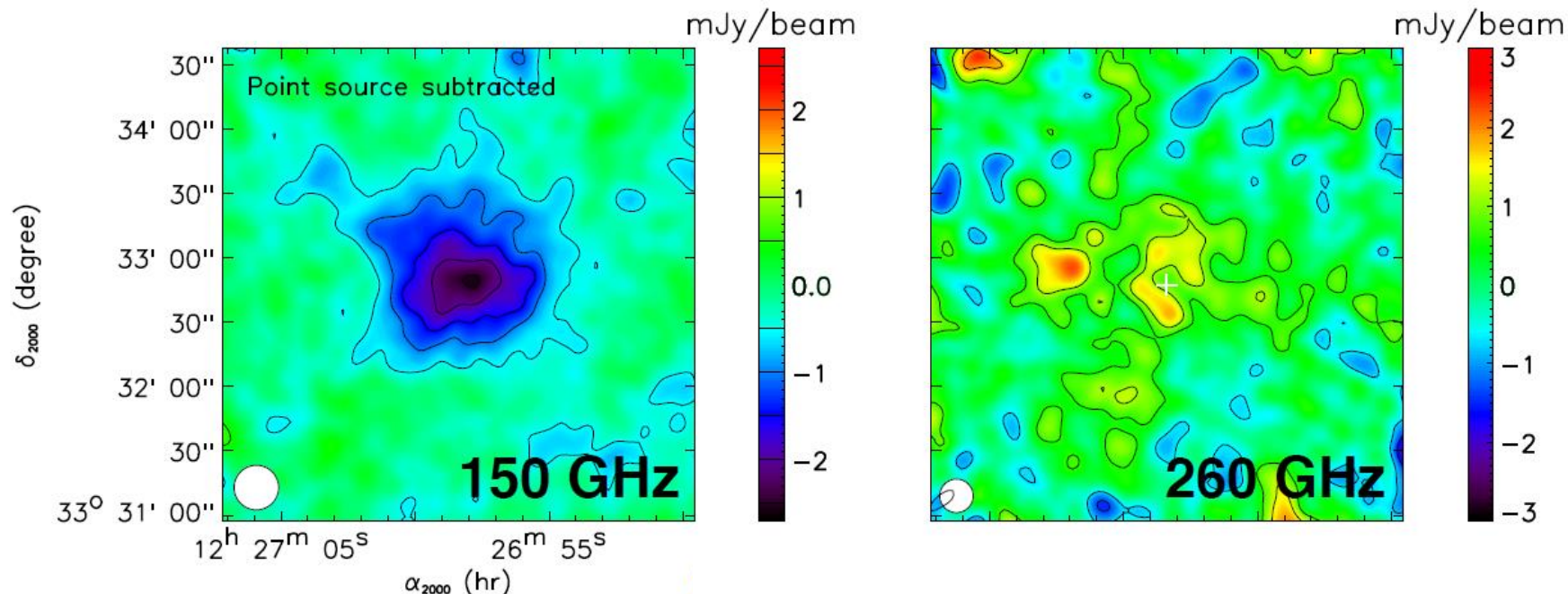


- SZ detection at 18σ
- SZ peak well aligned on X-ray center (white cross)
- Point source identified on the 260-GHz map
 - compensates the negative SZ signal at 150 GHz
 - **Point-source subtraction is needed**

High-z cluster: CL J1227 ($z=0.89$)



Point source subtracted



Feb. 2014

Obs. time: 7.8 h

R. Adam *et al.*, A&A 2015

- SZ detected in the 2 bands with expected ratio
- To further remove atmospheric noise, a single-band method can be used
 → accurate mapping from 20'' to 3' (0,1 to 1 R_{500} at $z=0,9$)

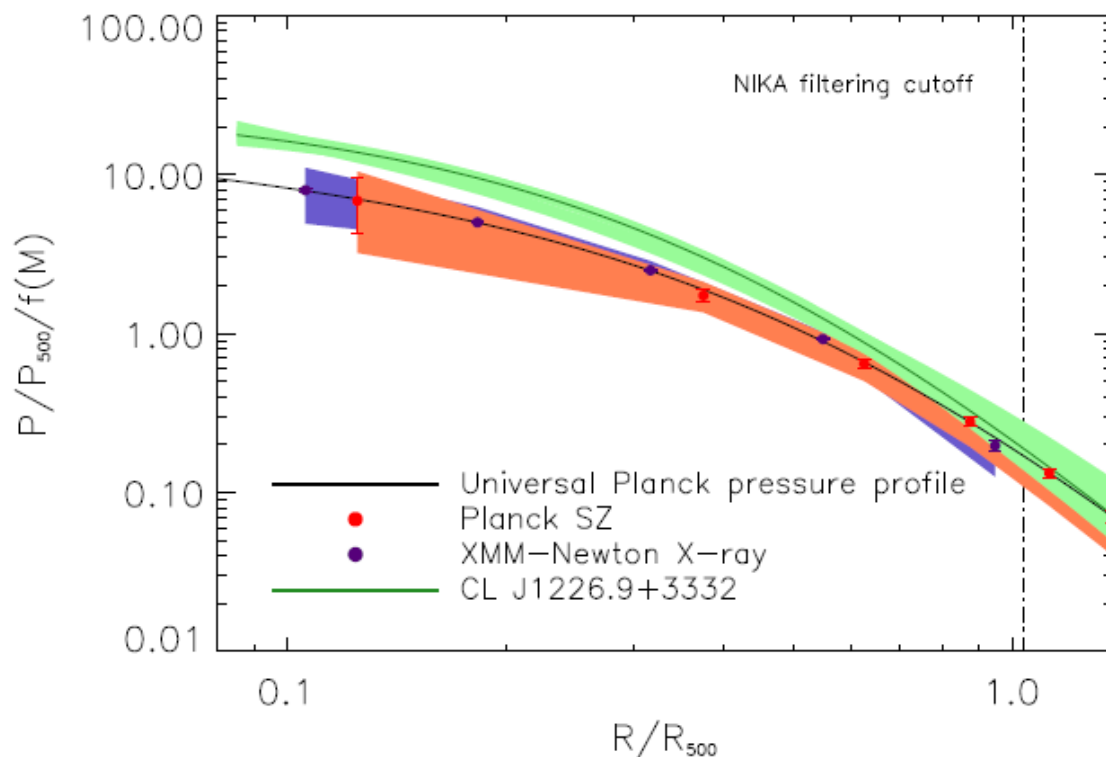
→ CLJ1227 is relaxed on large scales but with a disturbed core

High-z cluster: CL J1227 ($z=0.89$)

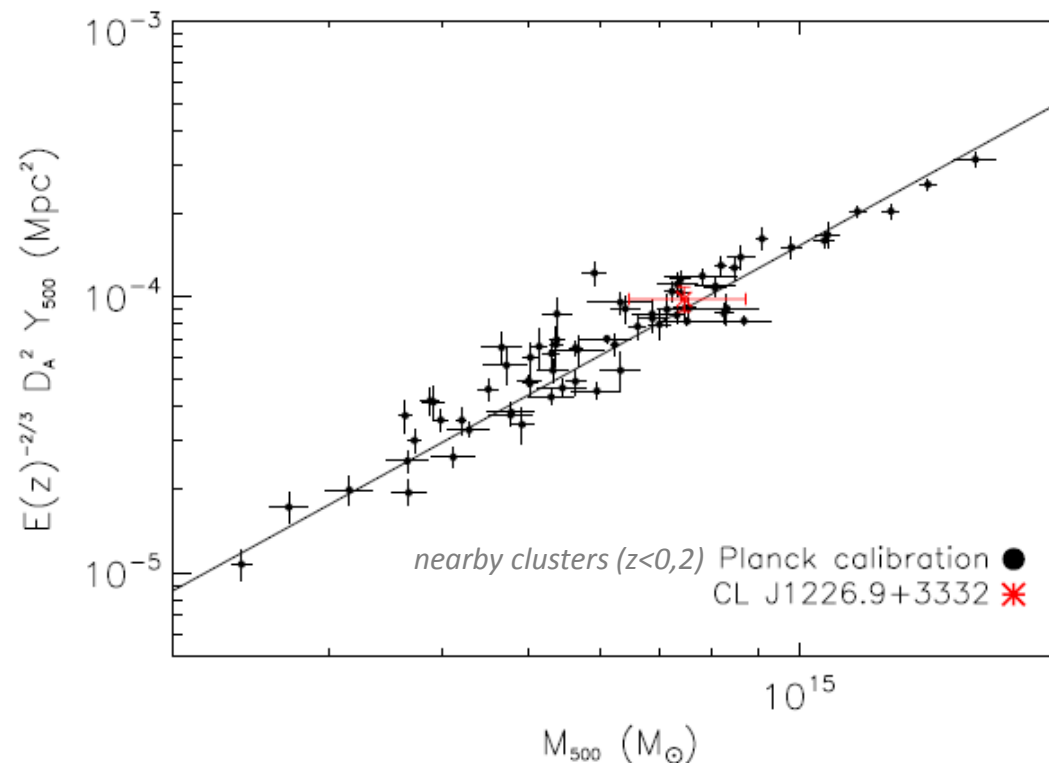


Comparison with the characteristics of low-redshift clusters

Pressure Profile



Mass/SZ flux scaling law



→ No conclusion can be drawn with a single high-redshift cluster

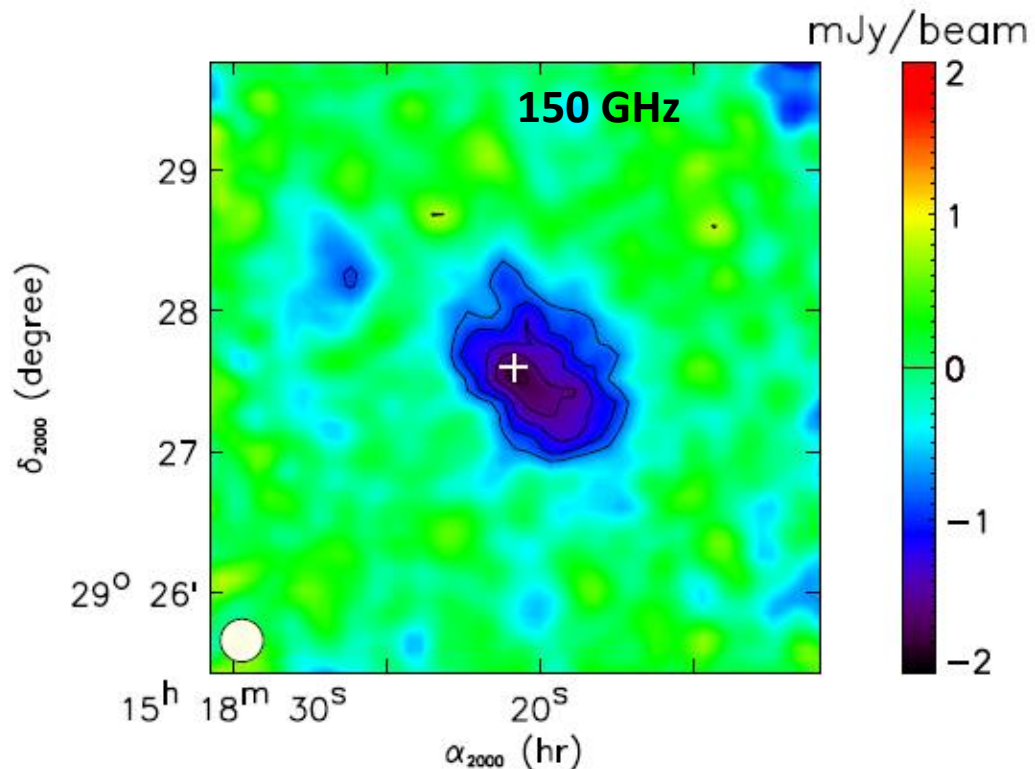
→ One of the goals of NIKA2 SZ Program

→ Redshift evolution of Pressure profiles and Mass/SZ relation

Planck-discovered cluster: PSZ1G045



Nov. 2014
 Obs. time: 5.5 h
 F. Ruppin *et al.*, arxiv 2016



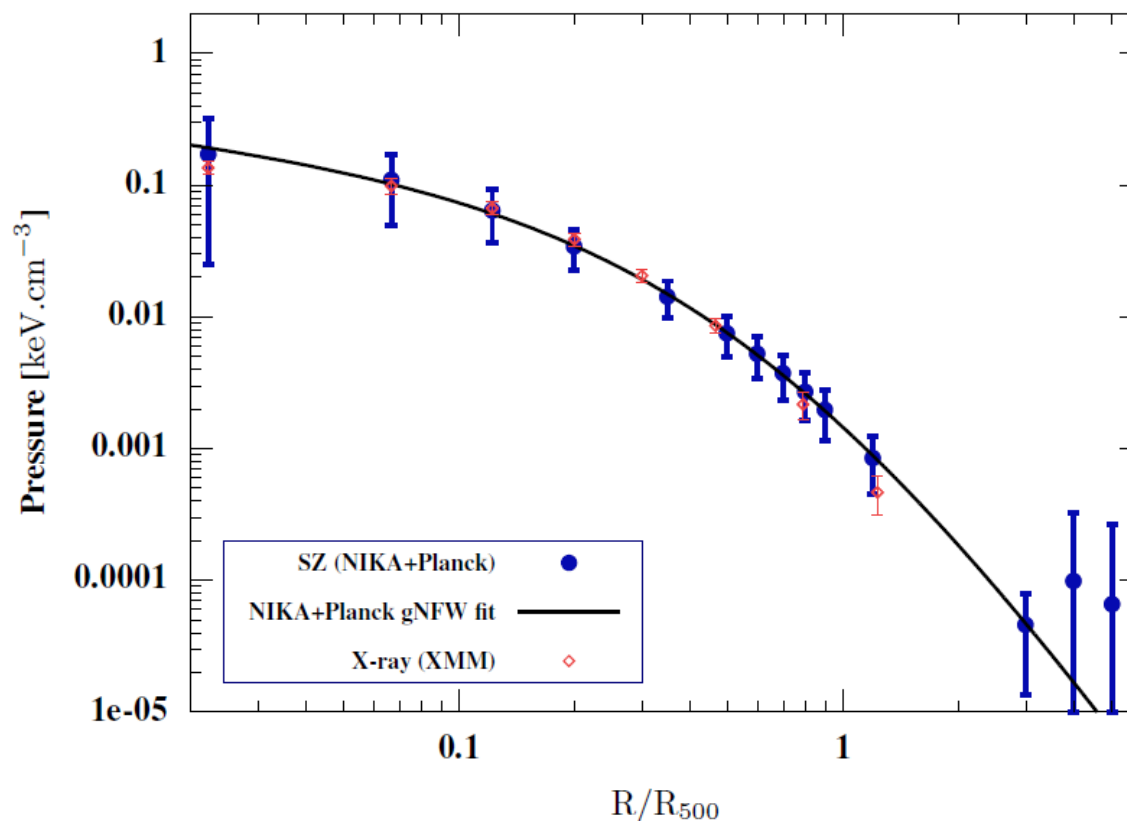
- 150-GHz map : SZ peak at 7σ
- the maximum SZ decrement is aligned with the X-ray peak
- 260-GHz map no significant SZ signal, no point sources

→ A pilot study done with NIKA to prepare the NIKA2 SZ program

Planck-discovered cluster: PSZ1G045



Nov. 2014
 Obs. time: 5.5 h
 F. Ruppin *et al.*, arxiv 2016



MCMC analysis based on a non-parametric model

Data = NIKA and Planck

→ constrain the values of the pressure from the cluster core to its outskirts

→ **Deprojection of the electronic pressure distribution**

→ Agreement with X-ray data (with spectroscopy... but time consuming)

→ Typical of the output product of the NIKA2 Large program (*a follow-up of 50 Planck-discovered clusters*)

Planck-discovered cluster: PSZ1G045



Combined analysis: Planck+NIKA+XMM

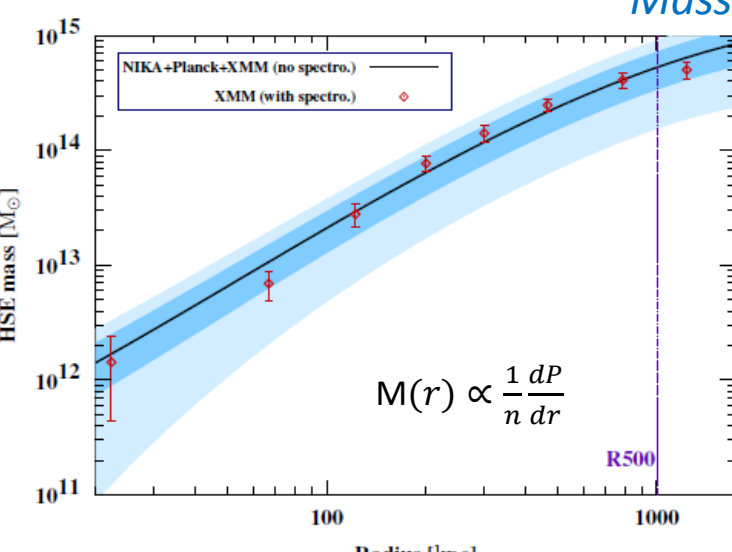
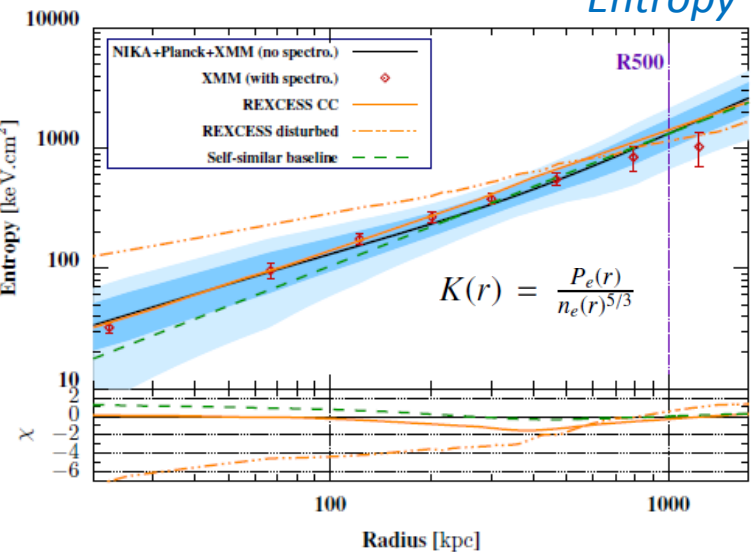
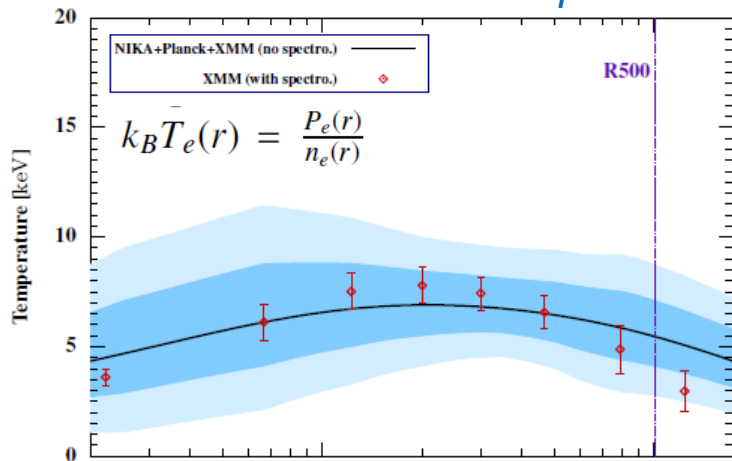
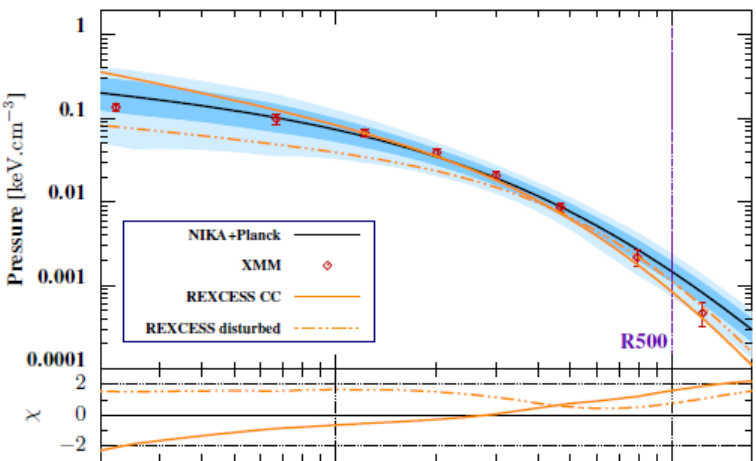
Nov. 2014
 Obs. time: 5.5 h
 F. Ruppin *et al.*, arxiv 2016

Pressure

Temperature

Entropy

Mass



- A Multi-probe study allows us to study the thermodynamic properties of the intra-cluster medium
- Comparaison with REXCESS sample (nearby clusters)
 - cool core (CC) and non-cool core (NCC)
 - P : CC or NCC
 - Entropy : this cluster is a cool core
 - T & M : agreement with XMM spectroscopic results.

→ PSZ1 G045.85+57.71 is a massive cool-core cluster.

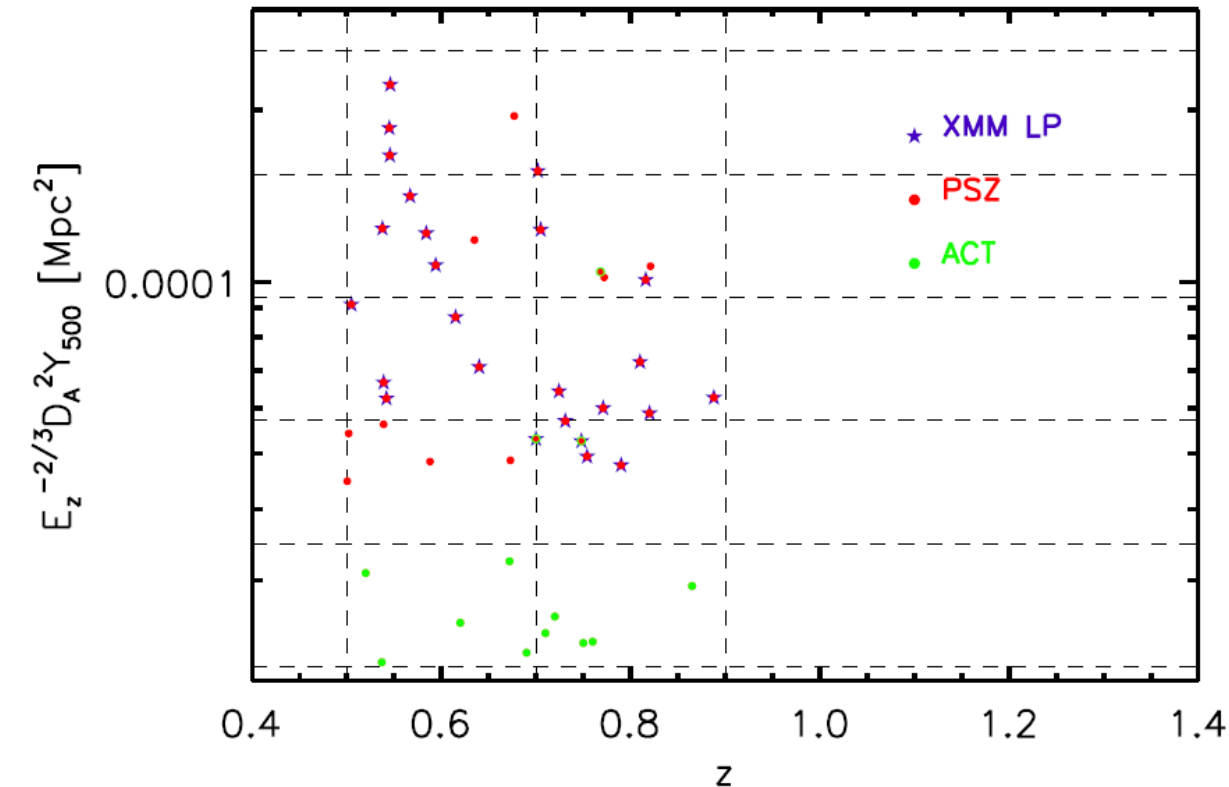
$$M_{500} = (5.4_{-3.0}^{+2.6}) \times 10^{14} M_{\odot}$$

$$Y_{500} = (5.61_{-0.59}^{+0.68}) \times 10^{-4} \text{ armin}^2$$

The NIKA2 SZ large program (2017-2022)



NIKA2 cluster sample



- one of the Large Programs of the NIKA2 Guaranteed time
 - 300 hours of observations
 - 50 clusters up to $z=1$ from *Planck* & *ACT catalogs*
 - *XMM follow-up*

Goals:

- in-depth study of the intra-cluster medium
- Combination with ancillary data (X, lensing)
 - **Thermodynamic properties of the ICM**
pressure, density, temperature, entropy, mass

Expected outputs:

- Redshift evolution of
 - pressure profile
 - scaling law and the hydrostatic bias
- Cluster properties as function of
 - dynamical states (mergers)
 - morphology (sphericity)

→ Significant improvements on the use of clusters of galaxies to draw cosmological constraints

NIKA2 Collaboration

